AGRICULTURAL WATER RESOURCES DECISION SUPPORT SYSTEM AND EVAPOTRANSPIRATION TOOLBOX

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ABSTRACT: There is a critical need for improvement in calculating and forecasting daily agricultural and riparian water use demands along the Middle Rio Grande. To help meet this need, an Agricultural WAter Resources Decision Support (AWARDS) system was implemented. This is an automated information system on the Internet designed to assist water managers and users by providing easy access to rainfall and crop water use estimates. These estimates are based on real-time data obtained from NEXRAD radar systems and automated weather stations. This paper presents the Bureau of Reclamation's development of an Evapotranspiration Toolbox (ET Toolbox) that builds on the AWARDS system, adding GIS land use to specify acreage for crop and riparian water use and open water evaporation estimates for 4-km grid cells. The primary purpose of the ET Toolbox is to accumulate the grid cells' daily rainfall and water use estimates within specified river reaches. These estimates are presented on the Internet and imported into RiverWare, which is the river modeling and water accounting system used by the Upper Rio Grande Water Operations Model (URGWOM).
KEY TERMS: Internet; NEXRAD; weather stations; evapotranspiration; water use.

INTRODUCTION

The Bureau of Reclamation (Reclamation) is developing an Agricultural WAter Resources Decision Support (AWARDS) and Evapotranspiration Toolbox (ET Toolbox) for estimating daily water use requirements at a resolution useful for implementation in the Upper Rio Grande Water Operations Model (URGWOM). The URGWOM is a multi-agency effort to develop a numerical computer surface water model that will cover the Rio Grande from Colorado to Fort Quitman, Texas. The primary purpose of this model will be a daily water operations accounting tool that can be used for basin-wide water management and planning.

The goal of the ET Toolbox project is to develop a methodology for automatically inputting daily riparian and crop water use estimates, open water evaporation estimates, and rainfall estimates to the URGWOM. The initial development work focused on the Middle Rio Grande area from Cochiti Dam to San Marcial, which is just south of the Bosque del Apache National Wildlife Refuge in New Mexico. ET of riparian vegetation and irrigated crops, and open water evaporation accounts for about 60 percent of the water depletions over this reach of the Rio Grande.

AWARDS

In late FY1997, Reclamation's Albuquerque Area Office became aware of a newly developed (AWARDS) system for the Lugert-Altus Irrigation district in southwest Oklahoma. The AWARDS system is an automated information system on the Internet designed to assist water managers and users by providing easy access to rainfall and crop water use estimates. AWARDS uses rainfall estimates based on data from the NEXRAD (NEXt generation weather surveillance RADar) radar systems and remote automated weather stations. The Albuquerque Area Office requested that the AWARDS system be implemented in the Rio Grande, primarily as the foundation for the development of the desired ET Toolbox. The purpose of the AWARDS system is to improve the efficiency of water management and irrigation scheduling by proving guidance on when and where to deliver water, and how much to apply (Brower and Hartzell, 1998). AWARDS systems that have been implemented east of the Continental Divide use the NEXRAD Stage III multi-sensor (radar and gage) hourly product produced by the National Weather Service's (NWS) River Forecast Centers (RFCs) (Hartzell et al., 2000).

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The Stage III products use the NWS Hydrologic Rainfall Analysis Project (HRAP) 4 km x 4 km resolution grid. Every hour, the Stage III data files are automatically collected into the AWARDS computer via file transfer protocol (FTP) from the RFCs. Automated weather stations in AWARDS system areas transmit surface weather data via radio signal, phone, or satellite to local computer systems. The daily and hourly data are then automatically collected from the local computer systems, via FTP, into the AWARDS computer. NWS 24-hour quantitative precipitation forecasts (QPF) are also automatically collected from the RFCs.

Various Geographic Information System (GIS) data resources are used, such as watershed, hydrologic, political boundary, irrigation district conveyance system, and other features, for developing the base maps for the AWARDS system. These data are transferred to longitude-latitude coordinates for input to a graphics program available from the National Center for Atmospheric Research, called NCAR Graphics. The HRAP grid cells are plotted and overlaid with the NEXRAD precipitation estimates and weather station rain gage measurements. Once the day's data are accumulated, computer programs produce 24-hour summaries and make them available on the Internet site images. Lastly, the Modified-Penman based ET crop water use estimates, weather data, QPF, and ET forecasts are integrated into the images via pop-up charts. Reservoir operators, water managers, and on-farm water users access the AWARDS system products via the Internet to make their operational decisions.

ET TOOLBOX

The ET Toolbox builds on the AWARDS system, adding GIS land use to specify crop, riparian, and open water acreage within each HRAP grid cell. Several GIS vegetation data sets that cover portions of the area were evaluated. The Middle Rio Grande Land Use Trend Analysis GIS Data Base for 1992/93 and aerial photography taken during a June 1999 ET field study are the current land use resources. All of the vegetation data sets are transposed to the HRAP grid cell resolution and compared to determine changes in the vegetation and water depletion over time. An Ikonos satellite 4-meter multi spectral resolution land use data set from July 2000 is planned for use commencing with the 2001 irrigation season.

The primary purpose of this effort is to estimate daily rainfall and water depletions for each HRAP grid cell and the specified river reaches. These daily ET estimates and summary year-to-date cumulative ET estimates are available to users and water managers via the Internet. The daily cumulative river reach ET estimates are provided to the URGWOM by RiverWare, using a Data Storage System developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center.

Figure 1 is an example of the Rio Grande Basin ET Toolbox Project area, available from Reclamation's NEXRAD website at http://www.usbr.gov/rsmg/nexrad. The area from Alcalde, New Mexico to the southern boundary of the Middle Rio Grande Conservancy District (MRGCD) is shown. The shaded 24-hr NEXRAD Stage III rainfall estimates are shown in inches for March 7, 2001, Mountain Daylight Time as received from the NWS West Gulf River Forecast Center (WGRFC). The white sub-window boxes are designed to include the agricultural areas between Rio Grande diversion dams that provide water to users within the MRGCD. Clicking within these white sub-window boxes allows the user to further pop-up detailed ET charts for each crop grown in the area. The small white boxes to the left of the sub-window boxes allow the user to pop-up the more detailed features of the ET Toolbox as shown in Figure 2. The white triangles link to the USGS Internet site offering near real-time streamflow and river stage information. Most of the features of the images in Figures 1 and 2 were imported from various GIS coverages. The MRGCD water distribution system is also shown. These maps are produced for the Internet site using the NCAR Graphics product.

Weather data

A requirement for computing evapotranspiration for the ET Toolbox is acquisition of appropriate daily weather data, which includes maximum and minimum temperatures, dew point temperature or relative humidity, solar radiation, wind speed, and rain gage measurements. The weather data are obtained from the New Mexico Climate Center at the New Mexico State University, The University of New Mexico's Sevilleta Long-Term Ecological Research Program, and the MRGCD. Daily data are used in the ET calculations, and the one-hour data are made available to the NWS for fine tuning NEXRAD Stage III rainfall estimates. Daily values are available for Internet access by clicking on the + signs in Figure 2 and hourly values are accessed from the Wx Station Hourlys box in Figure 1.

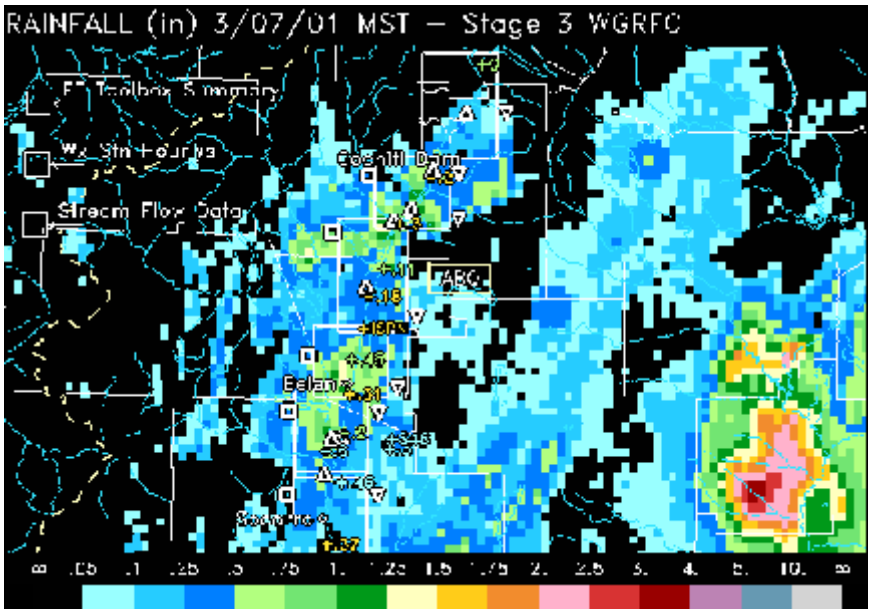

Figure 1. Example of an interactive image showing the 24-hr NEXRAD Stage III rainfall estimates.

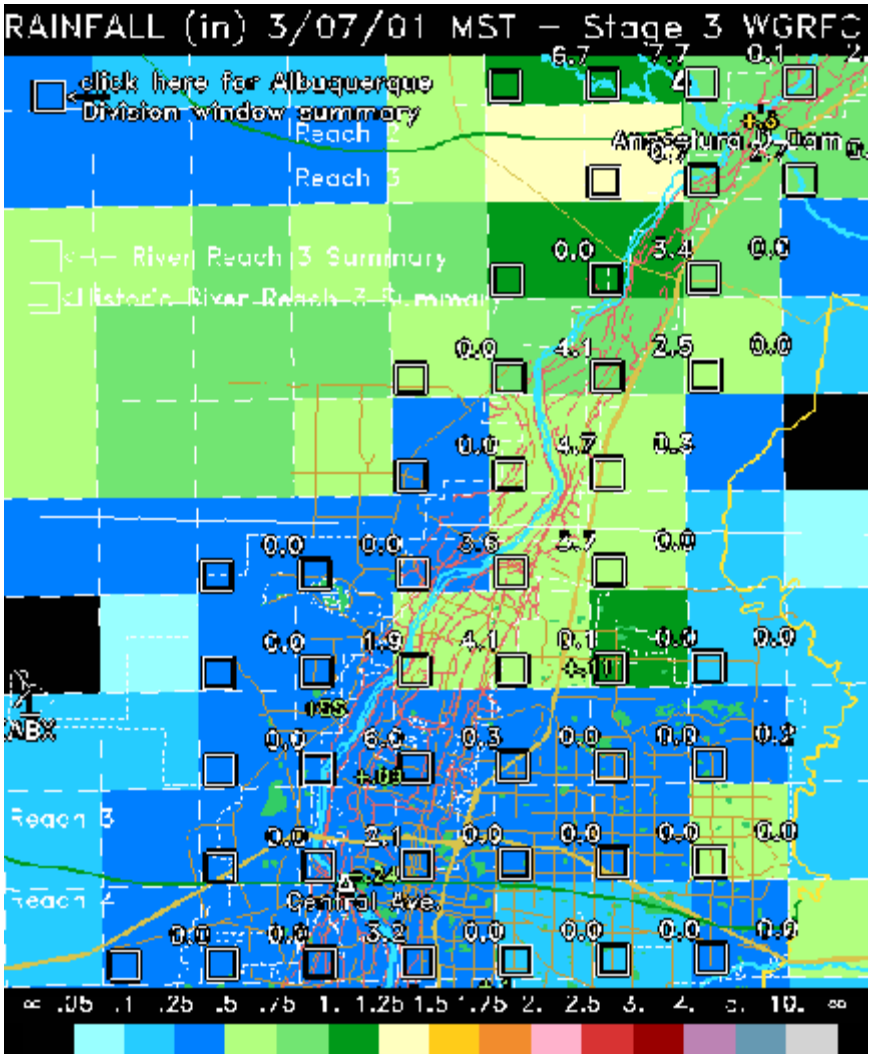

Figure 2. Example of an interactive image showing the grid cell 24-hr ET estimates and shaded 24-hr NEXRAD Stage III rainfall estimates.

Evapotranspiration

Researchers at the New Mexico State University chose a modified version of the Penman equation for calculating reference evapotranspiration (Eto). This value is empirically derived from experimental data based on a grass referenced method that combines energy balance and heat and mass transfer functions (ASCE, 1990). A crop coefficient (Kc) is applied to the Eto to determine the daily ET, in inches, as applied in the ET Toolbox, using the formula:

$$ET = Kc \times Eto$$

The crop coefficient Kc is based on the ratio of an estimated ET, as measured by lysimeter in the field, to Eto, as calculated from the Modified Penman equation using the daily weather data from each weather station. Crop coefficients are normally derived in conditions where crop growth is not limited by physiological factors, available moisture, disease, or other factors that might hinder plant growth. Graphs of crop coefficients can be presented as a function of time, seasonal growth stages, percent of effective cover from zero to 100, or Growing Degree Days (GDD). Sammis (1985) states that since the plant development depends on the heat units, a physiological clock can be developed based on GDD. Crop coefficients as a function of GDD developed under a particular climate condition can easily be transferred to areas with a different climate.

GDDs are accumulated heat that will contribute to plant growth and development from the period of planting until harvesting, or bud break to defoliation. The average method was chosen in New Mexico (King and Bawazir, 1998) for determination of GDD using:

$$GDD = ((\text{Daily Max. Temp.} + \text{Daily Min. Temp.}) / 2) - \text{Base Temp.}$$

where the maximum and/or minimum temperatures are replaced with cutoff temperatures when limits are exceeded. Negative GDD values are prevented.

ET Toolbox calculations and results

Computer processes were developed to collect all of the required data sets and calculate the daily consumptive use (DCU) in acre-feet for each crop using:

$$DCU = \text{Eto (in)} \times Kc \times \text{Acres} / 12 \text{ (in/ft)}$$

where Eto is the reference evapotranspiration in inches, Kc is the crop coefficient, and Acres is the crop acreage of the grid cell.

All of the crop and riparian (including open water) acre-feet values (DCUs) are summed to arrive at an estimated consumptive use for each cell. These cell values are printed to a pop-up interactive image on the Internet site as shown in Figure 2. By clicking on the printed value within the cell, a pop-up ET Toolbox cell detail table will appear. Pop-up cell summaries are available from the individual cell boxes shown in Figure 2.

Figure 3 is an example of a pop-up graph summary of daily water (consumptive) use for the area from Cochiti Dam to San Marcial for a time period in year 2000. The Total trace is influenced by rain, but the Agricultural, Riparian, and Urban traces are presented to show the water use had it not rained. Similar graphs are available on the website for all diversions and reaches within the area, including options for choosing 5 and 10-day running averages. The user can also interactively generate water use graphs by type for any time period.

Gaging information

Figure 4 is a schematic of the gaging system in the MRGCD. By clicking on a gage box, the user can pop-up a graph of the current conditions as of the last hour, as shown in Figure 5. A future edition will show real-time flow rates in the boxes, and pop-up still photographs or live videos of the gage will be available. The groupings on the right are the irrigation diversion points. The valley cross sections on the left indicate depletion analysis points defined by USGS gages (river reaches), and provide graphs of discharge against the daily ET for that river reach.

Reclamation and MRGCD water operations staff use the ET summary and gaging data to better manage daily water releases from the reservoirs while satisfying downstream water use requirements for agricultural crops, riparian vegetation, open water evaporation, and fish & wildlife.

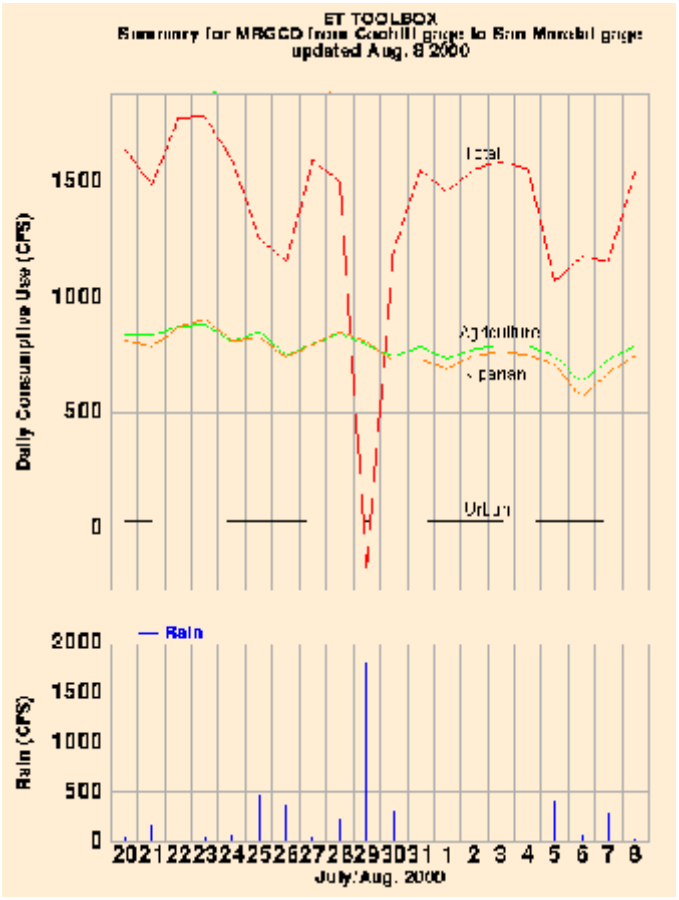

Figure 3. Example of a pop-up daily water use graph.

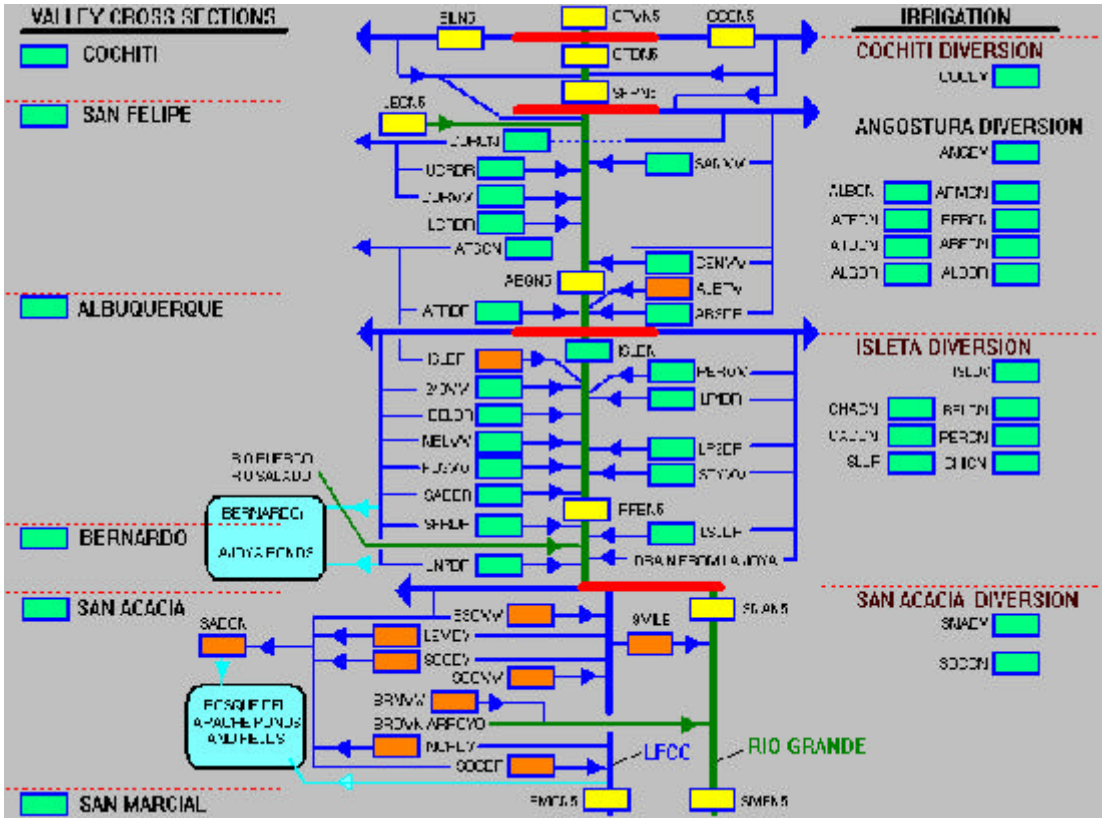

Figure 4. Schematic of the Middle Rio Grande Conservancy District Gaging System.

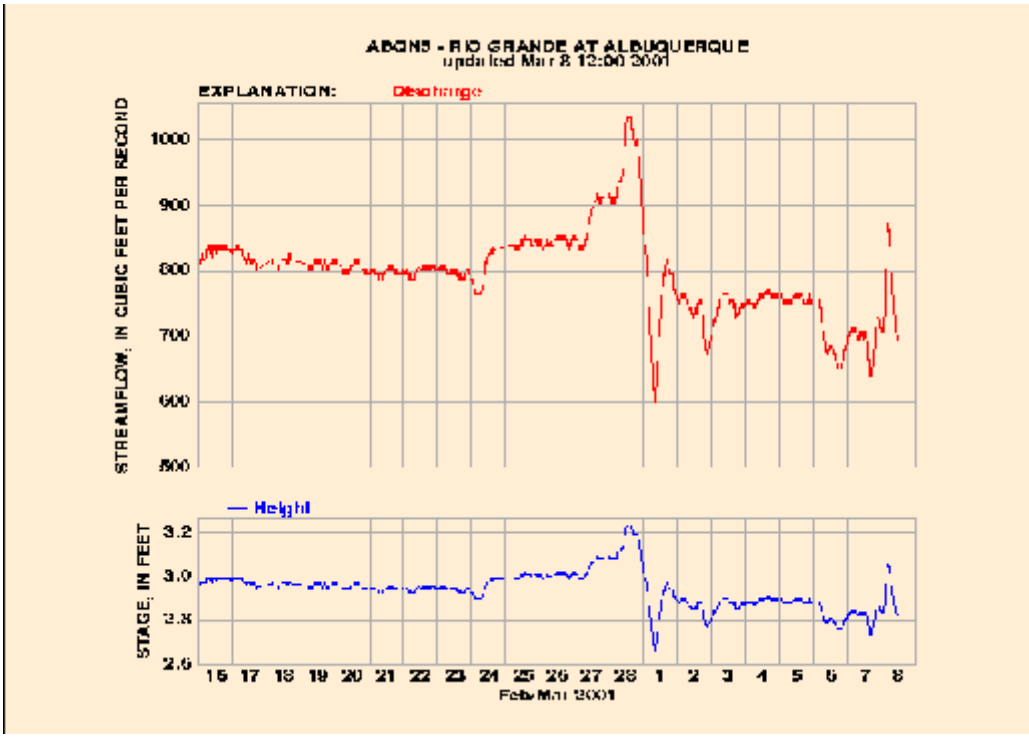

Figure 5. Example graph of discharge and river stage conditions.

SUMMARY

1. The AWARDS and ET Toolbox system demonstrates a methodology that integrates NEXRAD Stage III rainfall estimates, weather station data, crop and riparian ET requirements, GIS information, and land usage with modern computer, communication, and Internet technologies for improved water resources management.
2. Daily crop and riparian water use estimates for improving water management of the Rio Grande Basin are easily available for the specific crops and riparian growth in each 4 km x 4 km HRAP grid cell area.
3. Near real-time water use data are available for the Upper Rio Grande Water Operations Model via the RiverWare basin modeling system.
4. Water operations staff have a tool for managing reservoir water diversions to satisfy water use requirements

ACKNOWLEDGMENTS

The following individuals provided technical and administrative support for this work: Steve Hansen, Steve Bowser, Salim Bawazir, David Gensler, Tom Pruitt, and Ra Aman. We express our appreciation to those who reviewed this paper for AWRA.

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